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DESIGN OF DC-AC INVERTER LC FILTER FOR SOLAR POWER SYSTEM

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Abstract

The solar power system has a great future as clean energy instead fossil fuel, which has implemented in many utilities. An inverter is used to convert direct-current (dc) from solar power generation system to be alternating-current (ac) for utility applications. The output signal of the inverter contains many unwanted frequencies. This research proposes a filter is needed to get the smooth waveform at 60 Hz. The filter circuit which designed is a low pass LC filter to reduce total harmonic distortion. The values of the components of filter are calculated using a procedure described in this paper. Simulation of the circuit is done by Multisim Software v.7. In the circuit simulation, the input filter frequency is varied using function generator. A Bode plotter and an oscilloscope are used to observe the filter gain response and filter output. The simulation result presents that the filter output signal has a smooth waveform although the total harmonic distortion is still high.

Keywords: LC filter; total harmonic distortion; waveform

Sistem tenaga matahari mempunyai masa depan cerah sebagai energi yang bersih daripada bahan bakar minyak, dan telah dipergunakan dalam berbagai peralatan. Inverter digunakan untuk mengubah arus searah (dc) dari sistem pembangkit tenaga matahari menjadi arus bolak-balik (ac) untuk digunakan pada berbagai peralatan. Sinyal keluaran inverter mengandung banyak frekuensi yang tidak diinginkan. Penelitian ini mengajukan suatu filter yang diperlukan untuk mendapatkan bentuk gelombang yang halus pada frekuensi 60 Hz. Rangkain filter yang dirancang adalah filter LC low-pass untuk mengurangi total distorsi harmonic. Nilai-nilai komponen filter dihitung dengan prosedur yang akan dituliskan dalam paper ini. Pada simulasi rangkaian, frekuensi masukan filter diubah-ubah menggunakan pembangkit frekuensi. Plotter Bode dan osiloskop digunakan untuk mengamati tanggapan penguat dan keluaran filter. Simulasi rangkaian ini dilakukan dengan software Multisim v.7. Hasil simulasi menunjukkan bahwa gelombang sinyal keluaran filter berbentuk lebih halus meskipun total distorsi harmonik masih tinggi.

Kata kunci: filter LC, total distorsi harmonic, bentuk gelombang

Introduction

The solar power system has a great future as clean energy instead fossil fuel, which has implemented in many utilities. An inverter is used to convert direct-current (DC) from solar power generation system to be alternating-current (AC) for utility applications. In general an inverter system consists of a DC-DC boost circuit, a DC-AC inverter circuit and a filter.

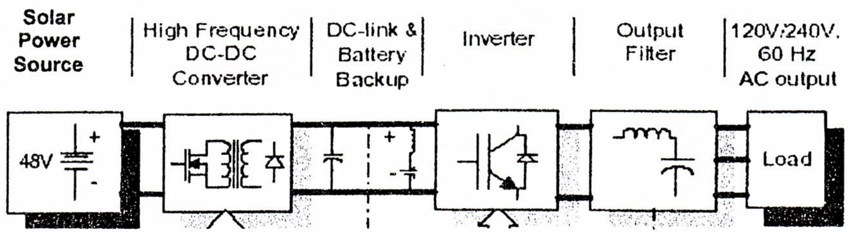


Figure 1. Block diagram of a general inverter

The low DC input from the solar power is first converted to a regulated high DC voltage using a high frequency DC-DC converter. The DC-DC conversion stage consists of a high frequency transformer. The DC-DC converter output is converted to 220 V 60 Hz, single - phase AC by means of a pulse width modulation (PWM) driven isolated gate bipolar transistor (IGBT), inverter stage. An output-LC filter stage is employed to produce a low total harmonic distortion (THD)-AC waveform.

DC-AC Inverter Output Filter

The pure output of the inverter, if monitored, is a square wave with varying duty cycles. This signal contains many unwanted frequencies including multiples of the PWM switching frequency (Figure 2). THD can be affected by these harmonics, therefore, the THD of the inverter can be reduced by using an output filter. This low-pass filter is designed to smooth out the waveforms generated from our DC-AC stage. The following section will describe the procedure used to find the appropriate values of the components of the filter.

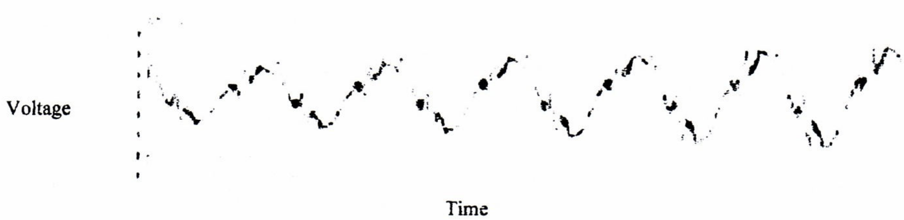


Figure 2. Inverter output contains many unwanted frequencies

Design Procedure

Figure 3 below shows the topology for the output filter. A transfer function is developed from the schematic.

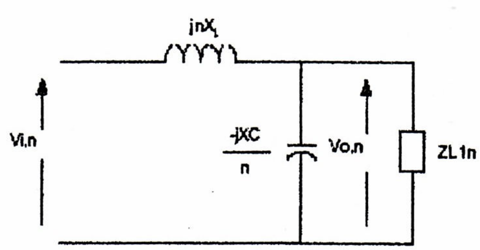


Figure 3. Topology of the output filter

The transfer function for this schematic is described by equation

$$H_n = \frac{V_{o,n}}{V_{i,n}} = -\frac{jX_C.Z_{L,n}}{nX_L.X_C + jZ_{L,n}(n^2X_L - X_C)} \quad \text{.........} \quad (1)$$

Where

H_n = transfer function

$V_{o,n}$ = output voltaic harmonic

$V_{i,n}$ = input voltaic harmonic

X_C = capacitor component of impedance

X_L = inductance component of impedance

$Z_{L,n}$ = impedance

n = harmonic

For $H_1 \rightarrow 1$; or $X_L << X_C$, then

$$H_1 << \frac{-jX_C.Z_{L,1}}{-jZ_{L,1}.X_C} \cong 1 \quad \text{.........} \quad (2)$$

Also, for a no load condition, $\infty \rightarrow 1$, $L\, Z$, therefore equation (1) is

$$|H_n| = -\frac{X_C}{n^2X_L - X_C} = \frac{1}{n^2\dfrac{X_L}{X_C} - 1} \quad \text{.........} \quad (3)$$

To satisfy a THD requirement of less than 5%

$$\frac{1}{n^2\dfrac{X_L}{X_C} - 1} \leq 0.045 = \frac{X_L}{X_C} \geq \frac{23.22}{n^2} \quad \text{.........} \quad (4)$$

An equivalent circuit used in finding filter characteristics for a non-linear load is shown in Figure 4.

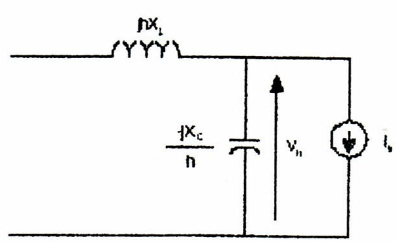


Figure 4. Equivalent circuit for a non-linear load

The transfer function for this schematic is described by equation

$$V_h = \frac{jhX_C.Z_L}{X_C - h^2X_L}.I_h \quad \text{.........} \quad (5)$$

Where

V_h = equivalent voltage

h = harmonic
I_h = current at h harmonic

Equation (5) can be shown as

$$|V_h| = \frac{hX_L}{1-h^2 \frac{X_L}{X_C}} .I_h \quad \text{(6)}$$

Here $\frac{X_L}{X_C}$ is very small making $h^2 \frac{X_L}{X_C} << 1$

$$|V_h| = hX_L.I_h \quad \text{(7)}$$

For the third harmonic $h = 3$,

$\frac{|V_h|}{V_1} = \frac{3X_L.I_3}{V_1}$, where THD is $\frac{|V_h|}{V_1} = 0.03 = 3\%$. Inductor impedance can be found by

$$X_L = \frac{0.03V_1}{3I_3} \quad \text{(8)}$$

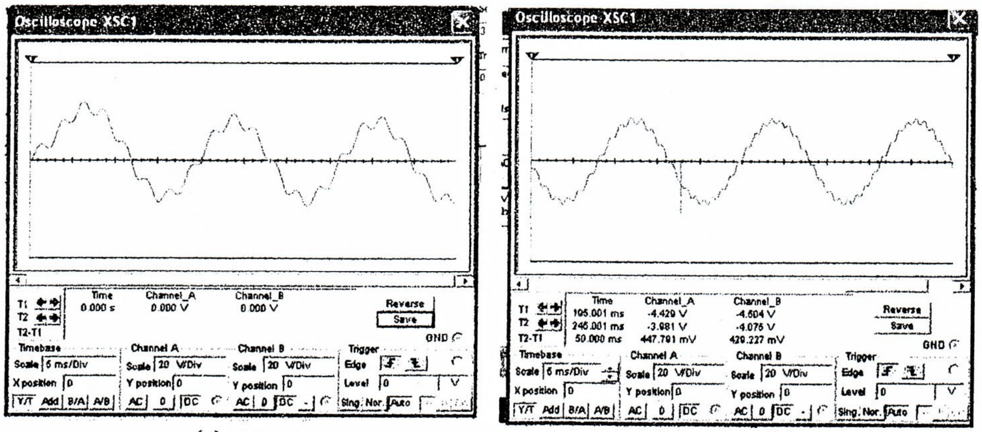
For circuit simulation, switching frequency f_s = 20 KHz and fundamental frequency f_1 = 60 Hz are taken. With $n = \frac{f_s}{f_1} = 333.33$ and $\frac{X_L}{X_C} >> 2.09x10^{-4}$, the filter resonant frequency f_r can be found with

$$\frac{f_r}{f_1} = \sqrt{\frac{X_L}{X_C}} \leq \sqrt{\frac{n^2}{23.22}} \leq 69.17 \approx 4{,}150Hz \quad \text{(9)}$$

Then for V_1 = 120 V, I_{rms} = 42 A = , I_3 = 26 A, X_L can be found by equation (8). Finally, the inductance L and the capacitance C for the output filter can be calculated.

Result and Discussion

The LC low pass filter circuit in Figure 3 is simulated by Multisim v7. The result of simulation is shown in Figure 5.



(a) (b)

Figure 5. Input (a) and output (b) signal of filter

In the simulation, the input of filter contains signal which has combined frequency between fundamental frequency (60 Hz) and multiples of the PWM switching frequency (20 KHz). The low pass filter makes smooth signal as shown in Figure 5, although the THD is still high (>15%). The filter characteristic shown in Figure 6 is appeared that the resonant frequency is 4,240 Hz. It means the circuit filter signal with frequency above 4,240 Hz.

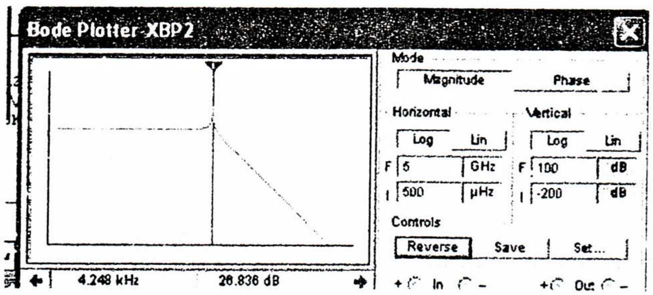


Figure 6. Filter characteristic

Conclusion

The design of an output filter for DC-AC inverter is described. Low pass LC filter could make smooth waveform at the fundamental frequency (60 Hz) although the THD is still high

Notation List

H_n	= transfer function	
$V_{o,n}$	= output voltaic harmonic	(V)
$V_{i,n}$	= input voltaic harmonic	(V)
X_C	= capacitor component of impedance	(ohm)
X_L	= inductance component of impedance	(ohm)
$Z_{L,n}$	= impedance	(ohm)
n	= harmonic	
V_h	= equivalent voltage	(V)
I_h	= current at h harmonic	(A)
f_s	= switching frequency	(Hz)
f_1	= fundamental frequency	(Hz)
f_r	= filter resonant frequency	(Hz)

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